GENERAL INFORMATION

Honeywell has a long history of providing highly reliable, superior quality products. We take four basic approaches to ensure high reliability of our products:

1. Our development program for new products includes extensive reliability simulation and analysis, such as thermal stress analysis and failure mode and effects analysis (FMEA).
2. The development program also includes exhaustive reliability testing, such as sensitivity to electrostatic discharge (ESD), mechanical and thermal tests, and accelerated life testing.
3. A sample from each wafer is subjected to reliability testing, including burn-in, before release of the wafer to production. Also, production processing includes environmental stress screening, typically burn-in, for products as necessary to ensure good reliability for devices shipped.
4. We continue to monitor product reliability and supplement our reliability database through our Product Reliability Monitor Program, which periodically subjects a large sample of production devices to a battery of reliability tests, including extended operating life testing.

This study summarizes the results of the extensive development reliability testing performed for the 850-nm Vertical Cavity Surface Emitting Laser (VCSEL) product. It is an update to the extensive reliability information published several times earlier, and demonstrates the reliability improvements made since that time.

OVERVIEW

The basic VCSEL component is the TO-46 style device (*e.g*. HFE4080, SV3637, or SV5637), which is the product discussed here. The data also applies to other VCSEL component package styles, such as pillpack (*e.g.* SV2637) and surface mount (*e.g.* SMV2637). Additionally, many other products, such as the VCSEL with back-monitor photodiode, connectorized VCSEL with back-monitor photodiode, and VCSEL-based OFE products incorporate the chip discussed.

CHIP STRUCTURE

The VCSEL construction comprises over 100 layers of gallium arsenide and aluminum gallium arsenide. These layers are grown with atomic precision using a process known as metal-organic vapor phase epitaxy (MOVPE, also known as MOCVD). Depending on the details of composition, doping, and thickness, various layers of these materials form a p-type semiconductor mirror, an n-type mirror, or a quantum well active region.

A schematic of the VCSEL is shown in the cutaway view of Figure 1. The scale of the figure is distorted to make features easier to see—actually all the MOVPE layers together occupy only the top 4% of the final chip thickness, and the light-emitting region is only 4% of the chip width. The VCSEL chip has metal n- and p-contacts and a proton-implanted region to force current to flow in the active region. The diameter of the current-confining implant is 20 µm, and the diameter of the metal opening is approximately 15 µm. Each of the many layers that comprise the device must function properly for the VCSEL to lase.

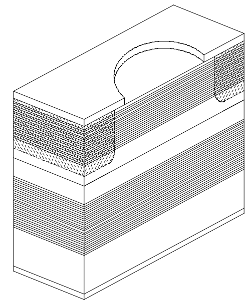

Figure 1: VCSEL Chip Structure

ELECTROSTATIC DISCHARGE STUDY

The ESD sensitivity of a product is of considerable importance, especially since devices with small active regions, like the VCSEL, are typically susceptible to ESD-induced damage. For these reasons, human body model ESD testing was performed on VCSELs from multiple wafers using MIL-STD-883D, method 3015.7. Subsequent 2000-hour burn-in was done to assess any latent defect caused by the ESD shock. The failure threshold was found to be above 700 V, which is somewhat more robust than identical testing showed for edge-emitting semiconductor lasers. It is important to note that all failures occurred immediately after application of the ESD shock; no significant latent ESD effect was found during the burn-in.

MECHANICAL TESTING

Mechanical testing has included air-to-air temperature cycling (100 cycles, -40°C to +100°C, five second transition time) per MIL-STD-750, method 1051 for 120 HFE4080 parts with no failures. Additionally, the same parts passed after constant acceleration testing (20 kg, Y1 axis) per MIL-STD-750, method 2006. Mechanical testing continues as part of our Product Reliability Monitoring Program.

LIFE TESTING SET-UP

The extensive life test study described in previous application notes and papers give long-term reliability data for nearly one thousand devices from more than five year's production. More than a dozen different combinations of burn-in and temperature were used, with several million actual device hours of burn-in performed; burn-in continued for more than 15,000 hours on some groups.

The accelerated life testing discussed here complements and updates the previous studies, taking into account device and process improvements made over the six years Honeywell has been shipping VCSELs. This current study employed a total of 666 devices using VCSEL chips from nine wafers (representing 3 growth and processing lots), with the wafers evenly split among the various burn-in groups. The chips were mounted in metal TO-46 style packages. Prior to the reliability study, all parts underwent the standard production screening burn-in. As usual, very few failures were found during the production burn-in.

The VCSELs were then subjected to operating life burn-in at 7 different combinations of temperatures, ranging from 100°C to 150°C, and constant dc currents, ranging from 10 mA to 30 mA, as summarized in Table 1. The temperatures and currents were chosen to give significant failure mode acceleration over the expected application conditions of less than 70°C ambient temperature and approximately 10 mA average operating current. Although extremely high, the acceleration was enough to achieve no failures or only a few failures in most samples. The parts experienced as much as 13,747 hours of burn-in, with a total of over six million device-hours of burn-in performed. Because it is now extremely difficult to provide enough life test acceleration to achieve failures (without compromising the results by introducing extraneous failure modes), this is the final report we will publish on proton VCSEL reliability.

Table 1: Reliability study matrix of forward current and ambient temperatures employed.

Group	Burn-In Condition	Burn-In Hours	Quantity Started	Quantity Failed
A	100°C, 15 mA	13,747	66	0
B	100°C, 20 mA	13,747	86	2
C	100°C, 30 mA	2504	88	52
D	125°C, 10 mA	13,747	89	0
E	125°C, 15 mA	13,747	87	2
F	125°C, 20 mA	1664	169	0
G	150°C, 10 mA	13,747	81	0

The devices underwent operating life testing in dark, forced-air ovens at constant dc drive current. Periodically, the devices were removed from the burn-in chamber and tested at room temperature for optical output power and forward voltage at several current levels. This test scheme ensured that reliability data was taken when devices were near the expected use temperature (around room temperature), rather than at the burn-in condition. Similarly, although both burn-in and room-temperature testing were done at multiple operating currents, the test current used for generating reliability data was 10 mA for all parts. This current is close to the average operating current expected in many VCSEL applications.

The failure criterion selected was a 2 dB drop in total optical output power relative to the power measured before starting life testing. This 2 dB criterion was chosen over the more common 3 dB change to minimize the link budget required to be allocated for transmitter degradation. Analysis of the data showed that a 3 dB criterion would give about 10 - 20% longer lifetimes than the 2 dB criterion. Analysis for other commonly-used failure criteria, such as change in threshold current, also gave similar results. Extremely important is that all failures recorded were actual failures and not extrapolations to failure.

FAILURE RATE DISTRIBUTION

For each failing unit, the time-to-failure was recorded. Our test scheme of periodically removing parts from burn-in for test as described above caused the data to be interval-censored; exact times-to-failure were not known, only that failure occurred sometime during test intervals. The censored time-to-failure interval data for each group (with unfailed units as suspensions) was analyzed with a commercial reliability software package. In the one group where enough failures occurred, the data best fit a lognormal distribution (compared to the one-parameter exponential and two-parameter Weibull distributions), so the lognormal distribution was chosen as the failure rate distribution. That is, the plot of the failure probability density function versus operating time was found to be modeled best by the lognormal distribution.

The lognormal distribution is frequently used to describe the failure time data for semiconductor devices. For this distribution, the natural logarithm of the time-to-failure is distributed normally. The lognormal distribution, then, has two parameters: μ, which is the mean of the natural logarithm of the failure times, and σ, which is the standard deviation of the natural logarithm of the failure times. The median failure time (where 50% of the devices fail) for the lognormal distribution is given by e^{μ}.

Figure 2 shows the reliability improvements made recently through improved uniformity of the wafer parameters. This has resulted in a reduced σ from 1.29 given in the first study to the current value of 0.5. The result is a dramatic improvement in short-term reliability, which is the most important information for VCSEL users. For example, note in Figure 2 the hundred-fold improvement in reliability for 0.05% (500 PPM) failure rate.

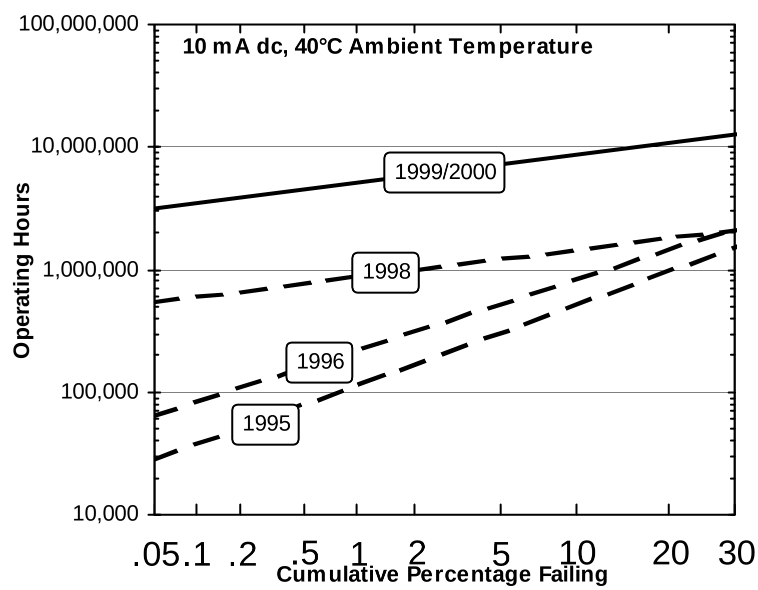

Figure 2: Comparison of lognormal reliability distribution fits for current product and earlier application note. Note the significant improvement in reliability for low failure rates.

ACCELERATION MODEL

Since there are more than 2 failures in only one life testing group, an acceleration model cannot be derived from this data. However, data reported in 1998 can be used to derive the model, as there is no reason to suppose the model has changed since then. So the discussion below is for that previous data-set, but still applies.

The acceleration model determined from the reliability study is the Arrhenius relation multiplied by a power-law current factor. This current factor is required to account for the effect of operating current on reliability over and above its effect on junction temperature. The acceleration model is given in terms of operating current I_F, junction temperature T_J (in K), Boltzmann's constant k_B, and activation energy E_A (derived below to be 0.7 eV):

(1) $$A.F. = {}^{TTF_2}/_{TTF_1} = \left({}^{I_{F1}}/_{I_{F2}}\right)^2 \times e^{E_A/k_B \times (1/T_{J2} - 1/T_{J1})}$$

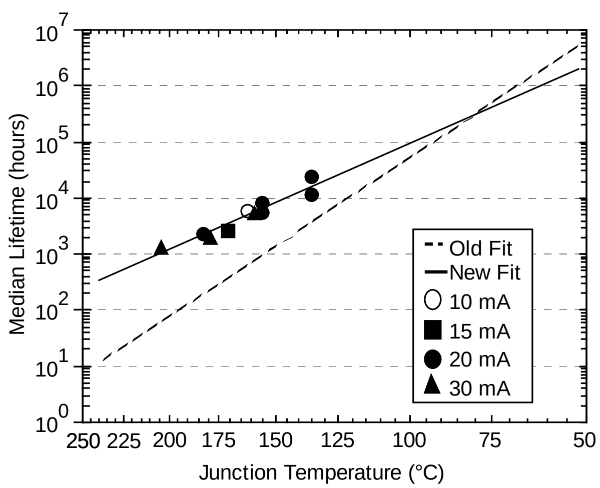

Figure 3: Arrhenius plot for lognormal median failure times adjusted by the current factor (I_F/10)^2 for September 1998 data. The best fit line is a weighted regression and has a slope corresponding to an activation energy of about 0.7 eV (denoted "New Fit" from September 1998, contrasted with "Old Fit" regression for data from March 1997). Distinct symbols represent different burn-in currents.

Note: this data is from previous study, reported September 1998.

This acceleration factor gives the ratio between two times-to-failure at different operating conditions; it is the ratio of operating times, not of failure rates. The power-law factor of 2 for the current effect was derived empirically from the Arrhenius plot shown in figure 3. The Arrhenius plot shows the current-corrected median times-to-failure (*i.e.* e^{μ}) obtained from the reliability study. The current correction is the square of the ratio of burn-in drive current (in mA) to a fixed current of 10 mA: $(I_F/10)^2$. Therefore, note that the points shown do not represent actual median time-to-failure data, because they have been adjusted by the current correction factor. The junction temperatures used for the Arrhenius plot represent the ambient temperature in the burn-in chamber plus the measured chip junction temperature rise due to the current-dependent power dissipation, excluding the power lost through optical emission.

The best fit line on the plot shows the acceleration model and was calculated from a regression of the weighted data. Note that the points appear to basically lie on a straight line, indicating that a single failure mode dominates throughout the range of junction temperatures tested. The activation (or extrapolation) energy calculated from the plot is about 0.7 eV. The Arrhenius with power-law factor model appears to adequately capture the effects of both temperature and current on reliability. Many wafer growths and fabrication lots are included in the data on this plot—the Arrhenius plot does not indicate any effect related to the different chip wafers having been used.

The Arrhenius plot shows the regression fits for both the March 1997 data (denoted “Old Fit,” corresponding to an activation energy of 1 eV) and September 1998 data (denoted “New Fit,” corresponding to an activation energy of 0.7 eV). The current data is believed to have the same acceleration model as the September 1998 data, although the lifetimes are better (that is the line shown on the graph is translated upward).

GUIDANCE FOR PREDICTING APPLICATION FAILURE RATES

The ultimate purpose of a reliability study is to provide a predictive tool that can be used to describe the likely future performance of a device in a specified application. Unfortunately, all such prognostications are subject to statistical limitations. The best we can do is use the failure distribution and acceleration models to establish the most likely performance, and use the statistics to determine the level of confidence we can have in our prediction. Keep in mind that the confidence intervals are widest in the very low (and very high) failure rate regions. Consequently, there can be much more uncertainty in reliability projections for small failure rates than for predictions of the MTTF, which is near the middle of the failure rate plot.

In this reliability study we have tried to reduce these statistical uncertainties as much as possible through both the quantity of data and breadth of sampling. The burn-in conditions used were significantly stressful to induce more than 50% failures in one group, which allowed us to confidently model the reliability distribution. Inclusion of multiple temperature and current stress combinations enabled us to confirm the failure acceleration model derived previously still applies. Several different types of analysis techniques with this and previous data confirmed that a single failure mode dominates in the 10 mA to 30 mA range of operating currents, and across the entire range of temperatures used.

Confidence in the predictions is further gained because we made as few assumptions and as little extrapolation as possible. All failures discussed were actual failures, not extrapolations to failure. The failure criterion used was a 2 dB drop in output power at the operating current expected to be used in typical applications: 10 mA average current at room temperature. Testing at the expected use conditions of 10 mA at room temperature reduces possible extrapolation errors when translating data from test conditions to use conditions. Note that if the operating current in the application is significantly above 10 mA, the reliability model presented here is conservative; that is, it would overestimate the failure rate.

Reliability in a particular application is not dependent on the VCSEL component alone. The physical environment (temperature, thermal conductive pathway, lead length, and airflow) as well as the “data environment" (data rate and encoding scheme) and duty cycle are also contributing factors.

The junction temperature of the VCSEL is a result of both the physical environment, which determines the ambient temperature and thermal impedance, and the "data environment," which determines the current through the device. If the current flows for a long time, say over 5 μs, relative to the measured VCSEL thermal time constant of about 1 μs, then the junction temperature is nearly constant at its steady state value. In that case, the reliability is given by the dc reliability factored by the duty cycle. If it flows for only a short time, say 250 ns or less, the junction does not have time to reach its steady state, and the temperature is lower, so the reliability is substantially better than the dc reliability. When the VCSEL is modulated with data in the intermediate range around 1μs, the junction temperature is constantly rising and dropping as the data changes from ones to zeroes. Reliability for these types of pulsed applications is discussed elsewhere.

With the extremely high lifetimes predicted by this model, freak failures will likely dominate for real-world applications. Freak failures, by their nature, cannot be predicted with this type of life study. However, because Honeywell is a high-volume manufacturer of VCSEL devices (many millions per year), we can use customer field history for such predictions. This data for 2000 was an estimated failure rate of 2 PPM, with average lifetime of these returned units being around 2 years. So both the reliability predicted from this internal study, and empirical data from field history confirms the high reliability of the Honeywell VCSEL.

PREDICTED APPLICATION FAILURE RATES

With the preceding caveats, Figures 4, 5, and 6 give reliability predictions for typical applications. The reliability data presented is applicable for the VCSEL packaged in TO-46, pillpack, and ceramic surface-mount packages. Keep in mind that confidence bands are implicit for the curves in the figures.

Bobby Hawthorne, Quality and Reliability Assurance Manager
September, 2001

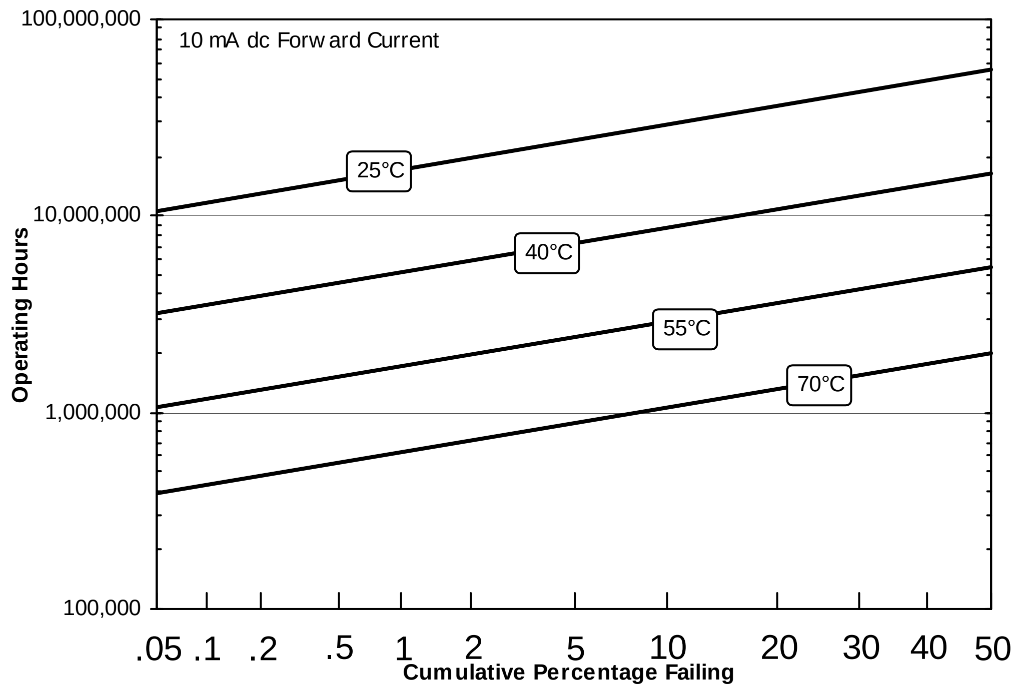

Figure 4: Cumulative failure plot for VCSELs operated at 10 mA dc forward current for several ambient temperatures.

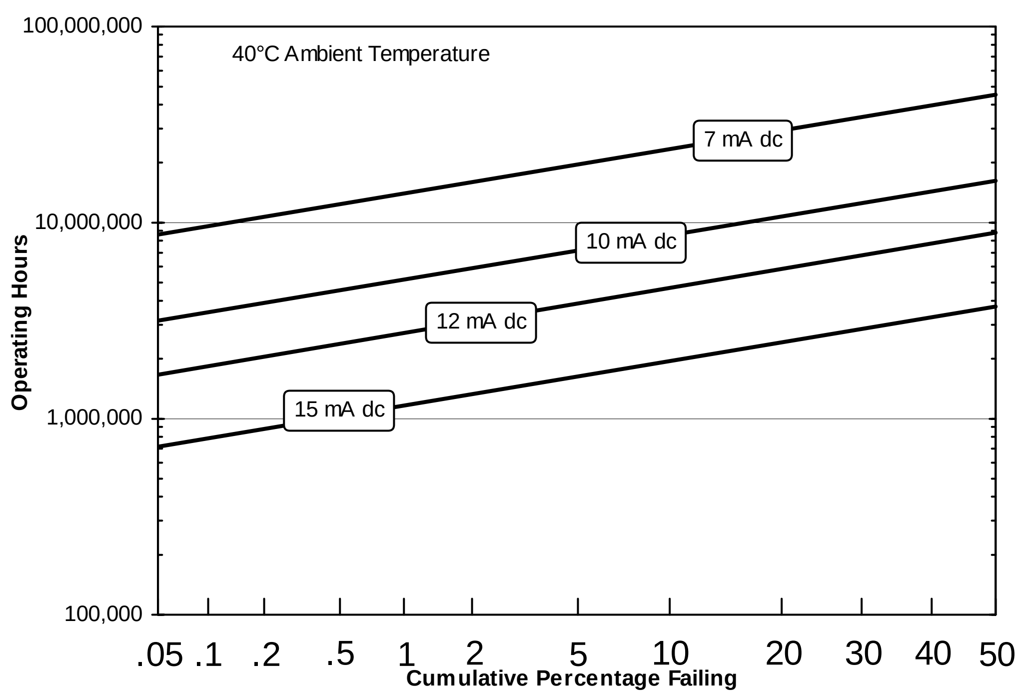

Figure 5: Cumulative failure plot for VCSELs operated at 40°C ambient temperature for several dc forward currents.

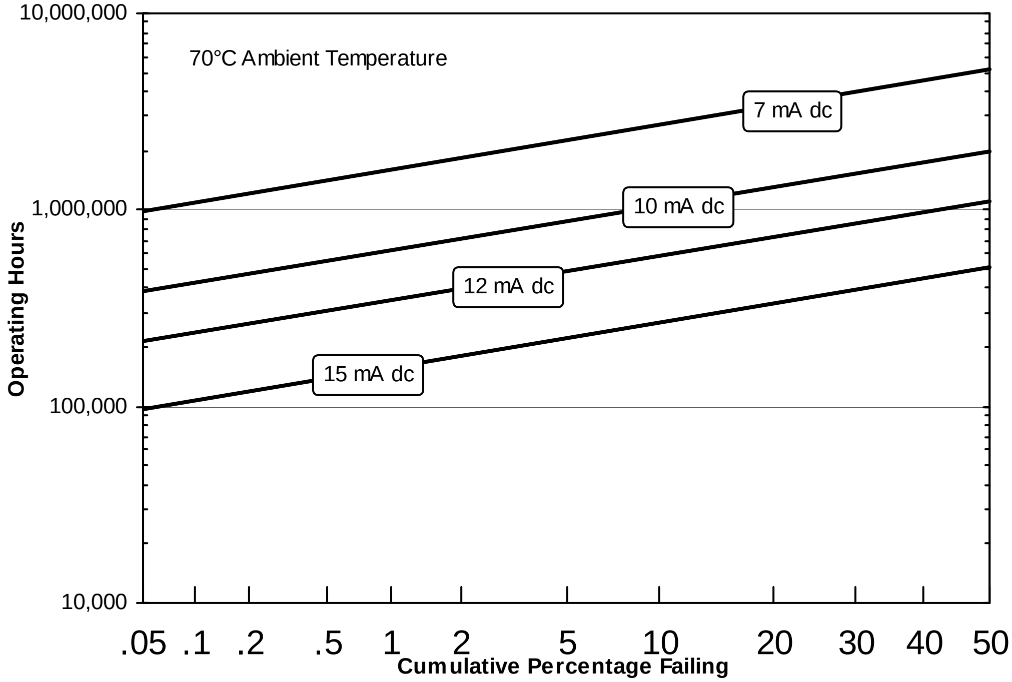

Figure 6: Cumulative failure plot for VCSELs operated at 70°C ambient temperature for several dc forward currents.

WARRANTY/REMEDY

Honeywell warrants goods of its manufacture as being free of defective materials and faulty workmanship. Commencing with the date of shipment, Honeywell's warranty runs for 18 months. If warranted goods are returned to Honeywell during that period of coverage, Honeywell will repair or replace without charge those items it finds defective. The foregoing is Buyer's sole remedy and is **in lieu of all other warranties, expressed or implied, including those of merchantability and fitness for a particular purpose.**

While we provide application assistance, personally and through our literature, it is up to the customer to determine the suitability of the product in the application.

Specifications may change at any time without notice. The information we supply is believed to be accurate and reliable as of this printing. However, we assume no responsibility for its use.

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